(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
18 December 2003 (18.12.2003)

PCT

(10) International Publication Number
WO 03/105509 A1

(51) International Patent Classification[7]: H04Q 7/32

(21) International Application Number: PCT/US02/18411

(22) International Filing Date: 11 June 2002 (11.06.2002)

(25) Filing Language: English

(26) Publication Language: English

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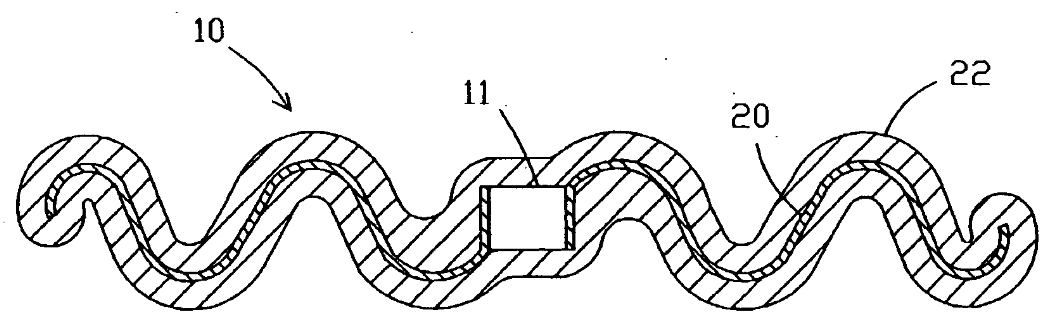
(81) Designated States *(national)*: AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NO, NZ, OM, PH, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VN, YU, ZA, ZM, ZW.

(84) Designated States *(regional)*: ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:
— *with international search report*

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

(54) Title: A RADIO FREQUENCY ANTENNA EMBEDDED IN A TIRE



(57) Abstract: A radio frequency antenna (20) for use with a radio device (11) embedded in a tire for operation in a frequency range of at least 130 MHz, comprises an antenna body, and an insulating coating (22) surrounding the antenna body, the insulating coating having a dielectric constant less than a dielectric constant of the rubber material, and preferably less than 3, and having a thickness of at least 0.2 mm. The coating material preferably has a surface resistivity of at least 10^{14} ohms/sq and a volume resistivity of at least 10^{11} ohms*cm. In addition, the coating material preferably has a dissipation factor less than 0.03. The antenna body is preferably a wire formed of spring steel, brass coated spring steel, or spring brass.

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A RADIO FREQUENCY ANTENNA EMBEDDED IN A TIRE

BACKGROUND AND SUMMARY

Electronic devices integrated in a tire provide functions such as identification and tracking during manufacture, distribution, and use, and measurement of physical parameters such as pressure and temperature during use of the tire. Many systems utilize radio frequency communication between the tire and the external monitoring or interrogating device. A radio frequency communication link requires one or more antennas.

There are available systems that mount to a surface of the tire or the wheel, or are incorporated in the tire inflation valve. An electronic device and antenna embedded in a tire structure, that is, in the rubber material, is desirable as providing a permanent, tamper-proof integration. Embedding the antenna in the tire, however, presents difficulties. The antenna must radiate radio frequency through the surrounding elastomeric material, which is usually electrically conductive, and which has a relatively high dielectric constant, typically 3 or greater. Conductive material in contact with an antenna tends to dissipate the radio frequency energy traveling on the antenna surface. In addition, conductive dielectric material in contact with an antenna allows radio frequency current to pass between the two adjacent feed points of the antenna, also dissipating radio frequency energy. The problem of dissipation increases with the frequency, and is particularly troublesome at or above very high frequency (130 MHz) operation.

In addition, the antenna, typically a metallic element, must adhere to the rubber material to secure it in place.

The invention provides a method for embedding a radio frequency antenna in a conductive elastomeric material, such as tire rubber, that allows for very high frequency or higher radio transmission from the antenna. According to the invention, the method comprises the steps of forming an antenna element, coating the antenna element with an insulating coating, the coating having a dielectric

constant lower than a dielectric constant of the elastomeric material and embedding the coated antenna element in the elastomeric material. Preferably, the coating is formed at least 0.2 mm thick, and more preferably, at least 0.3 mm thick.

According to another aspect of the invention, the coating material preferably has a surface resistivity of at least 10^{14} ohms/sq and a volume resistivity of at least 10^{11} ohms*cm. In addition, the coating material preferably has a dissipation factor less than 0.03.

According to another aspect of the invention, the antenna is tuned to compensate for the effect the dielectric elastomeric material has on the resonant frequency of the embedded antenna. The dielectric has the effect of making the antenna appear electrically longer than its physical length. The antenna, accordingly, is shortened, which is done by a series of iterations to determine the optimum length alone or with the aid of a network analyzer. Alternatively, the antenna could be adjusted by adding capacitive reactance in series at the feedpoint.

The invention also provides an antenna for embedding in rubber material of a tire suitable for transmission in a frequency range of at least 130 MHz. According to this aspect of the invention, an antenna includes an antenna body and an insulating coating surrounding the antenna body, the insulating coating having a dielectric constant less than a dielectric constant of the rubber material, and preferably less than 3, and having a thickness of at least 0.2 mm.

The antenna body can be any body capable of transmitting radio frequency energy. Advantageously, and preferably for use in a tire because of its durability under fatigue conditions, the antenna body is a wire formed of spring steel, brass coated spring steel, or spring brass. Such materials are capable of surviving the bending and flexing deformations typically experienced by the tire.

According to the invention, the coating material preferably has a surface resistivity of at least 10^{14} ohms/sq and a volume resistivity of at least 10^{11}

ohms*cm. In addition, the coating material preferably has a dissipation factor less than 0.03.

The invention will be better understood by reference to the following detailed description in conjunction with the appended drawings.

BRIEF DESCRIPTION OF THE DRAWING FIGURES

Figure 1 is a schematic of an electrical device having an antenna in accordance with the invention;

Figure 2 is a sectional view of a tire showing alternative placements for an electrical device with an antenna in accordance with the invention;

Figure 3 is a graph showing the effect of various insulating materials on the ability of a coated antenna to transmit through tire rubber material at 915 MHz;

Figure 4 is a graph showing the adherence strength of various coating materials; and

Figure 5 is a graph showing results of tuning an antenna and embedding it in an elastomeric material.

DETAILED DESCRIPTION

Illustrated in Figure 1 is a radio frequency device 10 for a tire including a radio device 11 and an antenna 12 in accordance with the invention. The radio device 11 itself may be an identification or tracking device, such as may be used in manufacturing, distribution, and sale activities. The device 11 may also be a monitoring device for measuring temperature, pressure or other physical parameters in an operating tire. For example, the antenna 12 in such a device is used to transmit to and/or receive from an external device information by radio frequency. As another example, the antenna may also serve to receive energy from an interrogation device. Such radio devices may operate as receivers,

transmitters, transponders or reflectors, and, because the antenna of the invention is useful for all these devices, in the following description, the term "radio device" is intended to be inclusive.

As shown in Figure 2, advantageously, the radio frequency device 10 may be positioned in a number of different places in a tire. A single tire may include one or several such devices, for example, if it is desired to monitor physical parameters at different locations in the tire or to monitor different parameters. The device 11 and antenna 12 may be embedded in a rubber patch 30 which is adhered to a surface of a tire 14. Alternatively, the radio device 11 and antenna 12 may be embedded in the tire structure itself or layered under rubber material in the tire 14 which forms a surface. For example, the radio frequency device 10 may be positioned between the carcass ply 16 and the inner liner 15, between the carcass play 16 and the sidewall 17, and/or between the belt package 18 and the tread 19. By "integrated" the inventors refer to either manner of incorporating the antenna 12 and radio device 11 in a tire.

Tire rubber material is usually electrically conductive, usually as a result of carbon black and other reinforcing fillers. Direct contact between a radio frequency antenna and tire rubber material is thus deleterious to the ability of the antenna to transmit energy.. Radio frequency energy travels along the surface of an antenna, in the so-called "skin effect." Conductive material in contact with the surface of the antenna tends to dissipate the energy through eddy currents. In addition, the conductive dielectric material allows radio frequency energy to pass between the two adjacent feed points of the antenna, which also dissipates energy. The result is a decrease in the effective transmission distance of the antenna. The inventors found that a device comprising a 915 MHz RFID chip having an antenna with a half-wavelength dipole length of 83 mm had a transmission range of 42 inches in air. When embedded in conventional tire rubber, the device had a transmission range of only 4 inches.

To overcome loss of effective range, the antenna 12 in accordance with the invention includes an antenna element 20 or body and an insulating coating 22. The embodiment shown in Figure 1 illustrate the antenna 20 as having a

sinusoidal form, which is advantageous for accommodating tensile forces in the tire material present in tire manufacturing operations and in normal tire operation. The antenna element 20 can be any element capable of transmitting radio frequency energy. For example, and preferably for use in a tire, the antenna element 20 is a wire formed of spring steel, brass coated spring steel, or spring brass. Such materials are able to withstand the kind of stresses experienced by a tire structure.

The coating layer 22 is formed of an insulating material and is at least 0.02 mm thick as measured perpendicular to the antenna. The thickness is sufficient to provide spacing between the conductive elastomeric material and the antenna 20 for avoiding bleed-through discharges to the elastomeric material. According to the invention, the coating material has a dielectric constant less than that of the elastomeric material, and preferably less than 3. In addition, the coating material preferably has a surface resistivity of at least 10^{14} ohms/sq and a volume resistivity of at least 10^{11} ohms*cm. Further, the coating material preferably has a dissipation factor less than 0.03.

The inventors have found materials useful for forming the coating material to include electrical shrink tubing, thermoplastic polycarbonate, butadiene rubber, an isocyanate-based rubber to metal adhesive such as Chemlok (brand) TS3604-50 adhesive (available from Lord Corporation, Chemical Products Division, 2000 West Grand View Boulevard, Erie, Pennsylvania), polyethylene, insulating varnish, epoxy, TPE cellulose acetate, polypara-xylylene (commonly known as "parylene"), and insulating polyester varnish. Such materials have certain advantages, including the ability to apply in the needed thickness. In addition, these coating materials have good adherence with both the antenna material (brass or steel in the described embodiment) and the rubber material of the tire or patch. Thus, an adhesive is not needed.

Figure 3 shows the results of exemplary antennas made with various insulating coating materials and embedded in a rubber substrate to simulate incorporation in a tire. The antennas were attached to a 915MHz RFID chip which acted as a transponder. As may be seen from the figure, an uncoated antenna

had a read range of about 4 inches. A first group, including shrink tubing, thermoplastic polycarbonate, butadiene rubber, and Chemlok (brand) TS3604-50 adhesive extended the read range to at least 35 inches. A second group, including insulating varnish, epoxy, TPE cellulose acetate, parylene, and insulating polyester varnish achieved lesser gains, but all were at least double the read range. Upon inspection, it was found that the second group had cracks in the insulation or other deficiencies in the thickness of the coating. The inventors believe that a coating thickness of at least 0.2 mm is sufficient to obtain a significant gain in read range, with a thickness of at least 0.3 mm being preferred.

According to another aspect of the invention, the insulating coating acts as an adhesive to bond the antenna to the rubber material. That is, the insulating coating has good adherence to both the antenna material and the tire rubber material. This aspect of the invention simplifies the manufacturing process by eliminating the need for one or two adhesives and the associated application steps. It is not critical, however, that the insulating coating perform this function, and the use of a separate adhesive is within the scope of the invention.

Figure 4 illustrates the results of testing various insulating coatings for adhesion strength in bonding an antenna wire having a brass outer layer (spring brass or brass coated spring steel) in tire rubber. Sample antenna wires were prepared, including an uncoated wire, and wires having, respectively, coatings of a rubber mix used for tire belts, Chemlok TS3604-50 (brand) adhesive, silica rubber, butadiene rubber, parylene C, parylene N, Bayer 9371 (brand) thermoplastic polycarbonate, and Bayer 2608 (brand) thermoplastic polycarbonate (available from Bayer Corporation, 100 Bayer Road, Pittsburgh, Pennsylvania 15205). These prepared antenna wires were cured in a sandwich of sidewall type rubber and carcass ply rubber mix. After cure, a peel test was done, with the resulting force needed to peel the rubber from the antennas shown in Figure 4. The highest peel forces were achieved by the antenna wires coated with belt rubber mix, Chemlok (brand) TS3604-50 adhesive, silica rubber, and the bare wire in a sidewall rubber.

By comparing the results shown in Figure 3 and Figure 4, it is noted that Chemlok (brand) TS3604-50 adhesive had the best combination of insulating characteristic (improvement in read range) and adhesive ability (peel strength).

A further step of preparing an antenna for use in a tire or in a rubber substrate involves re-tuning the antenna to adjust for the effect of embedding it in a dielectric material. Figure 5 shows the results of a test of antennas coated with standard electrical heat shrink tubing, cut to various lengths, and embedded in a typical cured and uncured tire sidewall rubber mix. Again, the antennas were connected to a 915 MHz RFID chip as the transponder. The horizontal axis shows the half-wavelength dipole length of the antenna in millimeters The vertical axis shows the read range in inches. As may be seen, an antenna in free air (not embedded in rubber) has a read range of about 48 inches with a half-wavelength dipole length of 83 mm. In an uncured rubber mix, the same length antenna had a read range of about 30 inches. In a cured rubber mix, the antenna had a read range of 12 inches. Tuning the half-wavelength dipole length to 47 mm restored the read range to 41 inches, and as shown, was the optimum for this configuration.

Tuning may be accomplished through iterations as suggested by Figure 5. Alternatively, a network analyzer could be used to determine the actual resonant frequency of the antenna embedded in the particular rubber to reduce the iterations required to find the optimum length.

Alternatively, the antenna could be adjusted by adding capacitive reactance in series between the antenna and the device at the feedpoint.

A method to embed an antenna in a tire or an elastomeric substrate according to the invention includes the steps of forming an antenna body, coating the body with an insulating coating at least 0.2 mm, and more preferably 0.3 mm thick, and curing the coated antenna body in an elastomeric material. According to a further step, the antenna wire is tuned prior to being embedded in the rubber material according to the procedure described above. Further, the coating material is selected in accordance with the properties described above.

The step of coating the antenna body could be accomplished by repeated dipping steps to build up the coating to the desire layer. Alternatively, the coating could be applied by spraying or other known techniques for applying coatings to wire-like materials.

The invention has been described in terms of preferred principles, embodiments, and structures for the purposes of description and illustration. Those skilled in the art will understand that substitutions may be made and equivalents found without departing from the scope of the invention as defined by the appended claims.

What is claimed is:

1. A radio frequency antenna for operation in a frequency range of at least 130 MHz for embedding in rubber material of a tire, comprising:
   an antenna body; and,
   an insulating coating surrounding the antenna body, the insulating coating having a dielectric constant less than a dielectric constant of the rubber material.

2. The radio frequency antenna as claimed in claim 1, wherein the coating is at least 0.2 mm thick.

3. The radio frequency antenna as claimed in claim 2, wherein the coating is at least 0.3 mm thick.

4. The radio frequency antenna as claimed in claim 1, wherein dielectric constant of the insulating coating is less than 3.

5. The radio frequency antenna as claimed in claim 1, wherein the coating material has a surface resistivity of at least 10^{14} ohms/sq, a volume resistivity of at least 10^{11} ohms*cm, and a dissipation factor less than 0.03.

6. The radio frequency antenna as claimed in claim 1, wherein the coating material is selected from a group comprising electrical shrink tubing, thermoplastic polycarbonate, butadiene rubber, isocyanate based adhesive, polyethylene, insulating varnish, epoxy, TPE cellulose acetate, parylene, and insulating polyester varnish.

7. A tire having a radio frequency antenna integrated therein, the tire comprising a carcass reinforcement and rubber material layers applied to said carcass, the antenna comprising:

   an antenna body; and,

   an insulating coating surrounding the antenna body, the insulating coating having a dielectric constant less than a dielectric constant of the rubber material.

8. The tire having a radio frequency antenna as claimed in claim 7, wherein the insulating coating is at least 0.2 mm thick.

9. The tire having a radio frequency antenna as claimed in claim 7, wherein the insulating coating is at least 0.3 mm thick.

10. The tire having a radio frequency antenna as claimed in claim 7, wherein dielectric constant of the insulating coating is less than 3.

11. The tire having a radio frequency antenna as claimed in claim 7, wherein the coating material has a surface resistivity of at least 10^{14} ohms/sq, a volume resistivity of at least 10^{11} ohms*cm, and a dissipation factor less than 0.03.

12. The tire having a radio frequency antenna as claimed in claim 7, wherein the coating material is selected from a group comprising electrical shrink tubing, thermoplastic polycarbonate, butadiene rubber, isocyanate based adhesive, polyethylene, insulating varnish, epoxy, TPE cellulose acetate, parylene, and insulating polyester varnish.

13. The tire having a radio frequency antenna as claimed in claim 7, wherein the antenna is embedded in a rubber patch adhered to a surface of the tire.

14. The tire having a radio frequency antenna as claimed in claim 7, wherein the antenna is embedded in a structural portion of the tire.

15. A tire having a radio frequency device integrated therein, the tire comprising a carcass reinforcement and rubber material layers applied to said carcass, the radio frequency device comprising:

a radio device which operates at a frequency of at least 130 MHz;

an antenna body connected to the transponder; and,

an insulating coating at least 0.2 mm thick surrounding the antenna body, the insulating coating having a dielectric constant less 3, a surface resistivity of at least 10^{14} ohms/sq, a volume resistivity of at least 10^{11} ohms*cm, and a dissipation factor less than 0.03.

16. The tire having a radio frequency antenna as claimed in claim 15, wherein the radio frequency device is embedded in a rubber patch adhered to a surface of the tire.

17. The tire having a radio frequency antenna as claimed in claim 15, wherein the radio frequency device is embedded in a structural portion of the tire.

18. A method for embedding a radio frequency antenna in conductive elastomeric material, comprising the steps of:

forming an antenna element;

coating the antenna element with an insulating coating, the coating having a dielectric constant lower than a dielectric constant of the elastomeric material, the coating being formed at least 0.2 mm thick; and,

embedding the coated antenna element in the elastomeric material.

19. The method as claimed in claim 18, wherein, the coating material has a surface resistivity of at least 10^{14} ohms/sq, a volume resistivity of at least 10^{11} ohms*cm, and a dissipation factor less than 0.03.

20. The method as claimed in claim 18, wherein the coating material has a thickness of at least 0.3 mm.

21. The method as claimed in claim 18, wherein the coating material is selected from a group comprising electrical shrink tubing, thermoplastic polycarbonate, butadiene rubber, isocyanate based adhesive, polyethylene, insulating varnish, epoxy, TPE cellulose acetate, parylene, and insulating polyester varnish.

22. The method as claimed in claim 18, further comprising the step of tuning the antenna for resonant frequency for the elastomeric material.

23. The method as claimed in claim 18, wherein the elastomeric material is a rubber patch, and further comprising the step of adhering the patch to a surface of a tire.

24. The method as claimed in claim 18, wherein the elastomeric material is a portion of a tire.

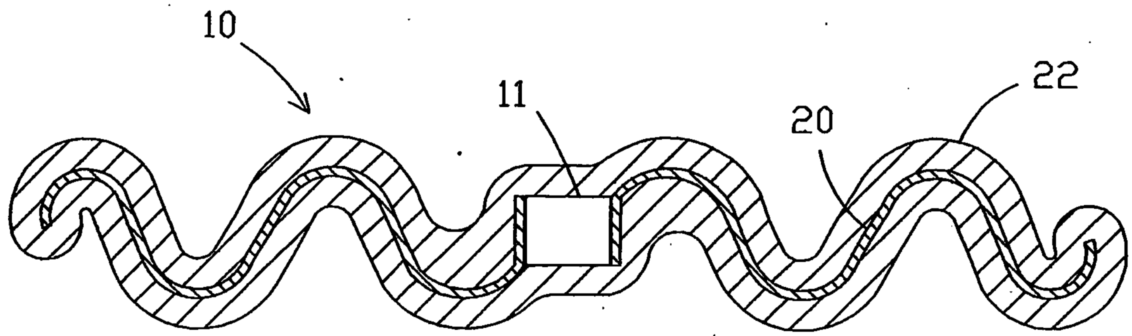


Figure 1

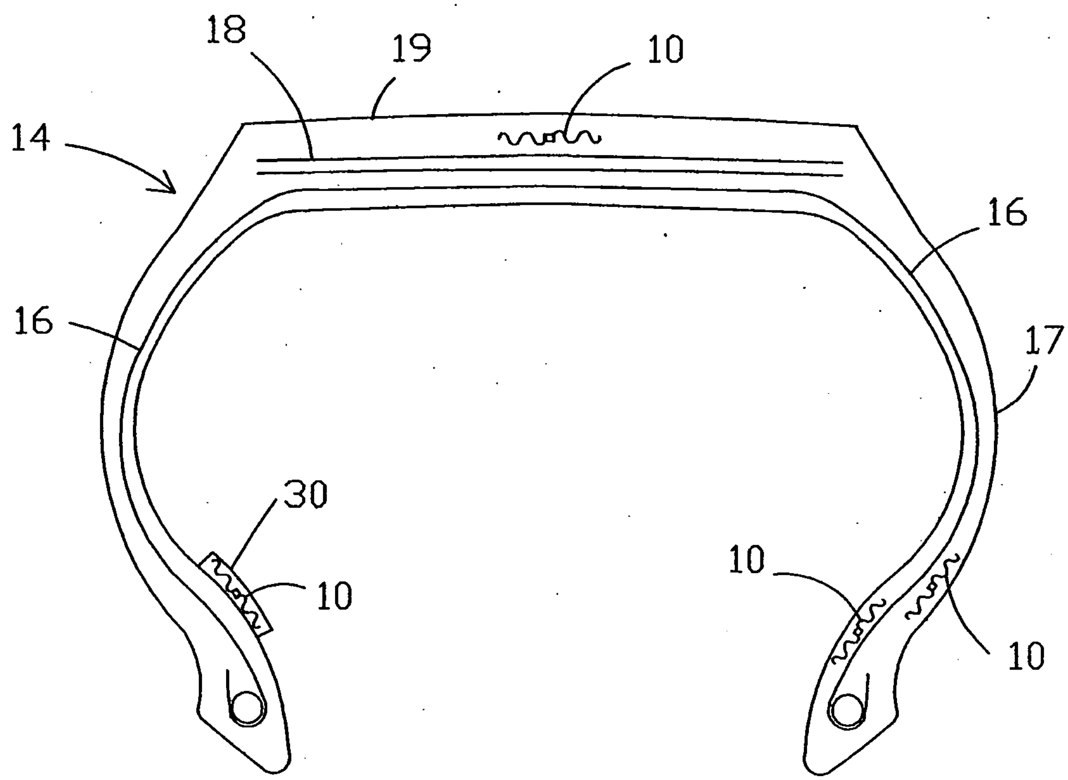
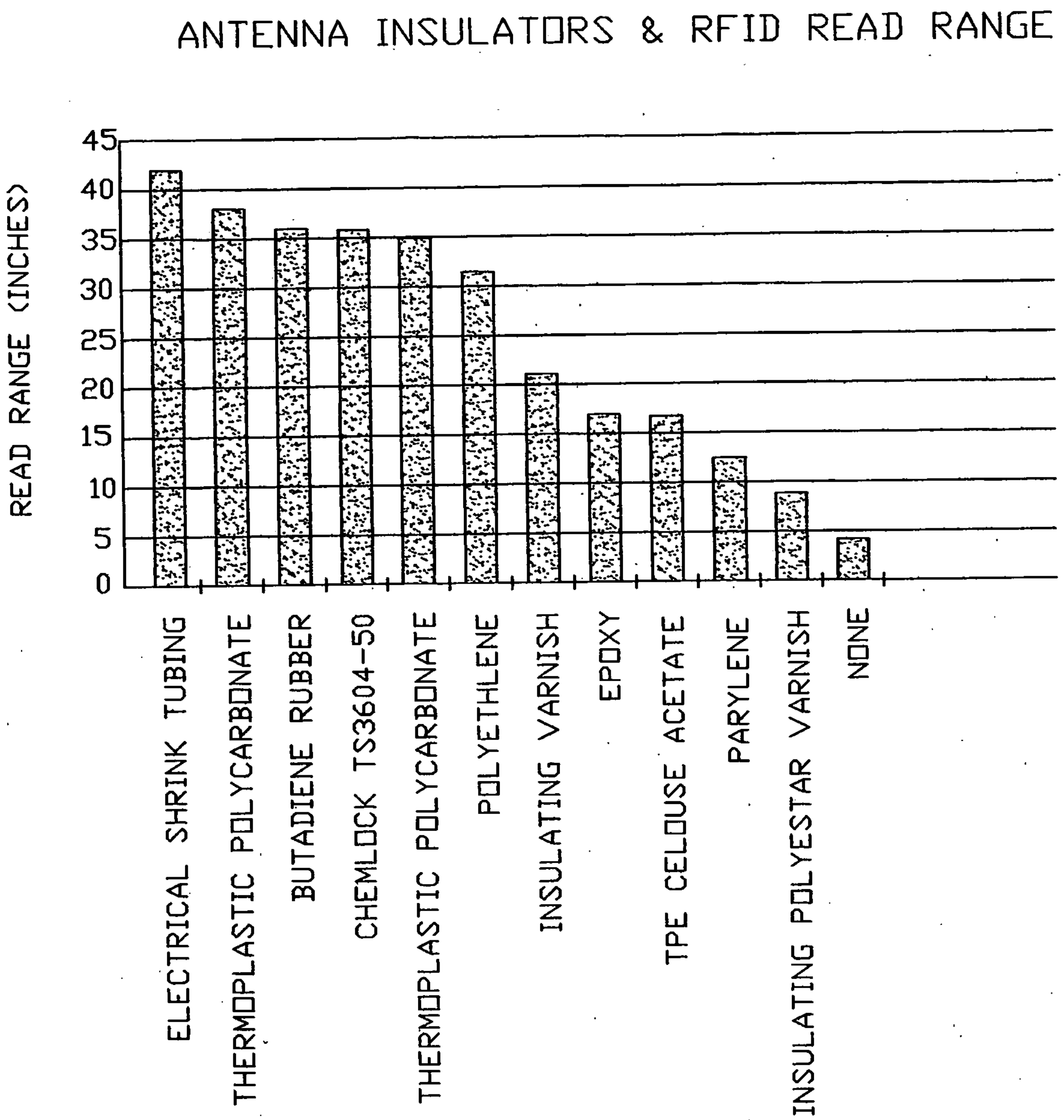


Figure 2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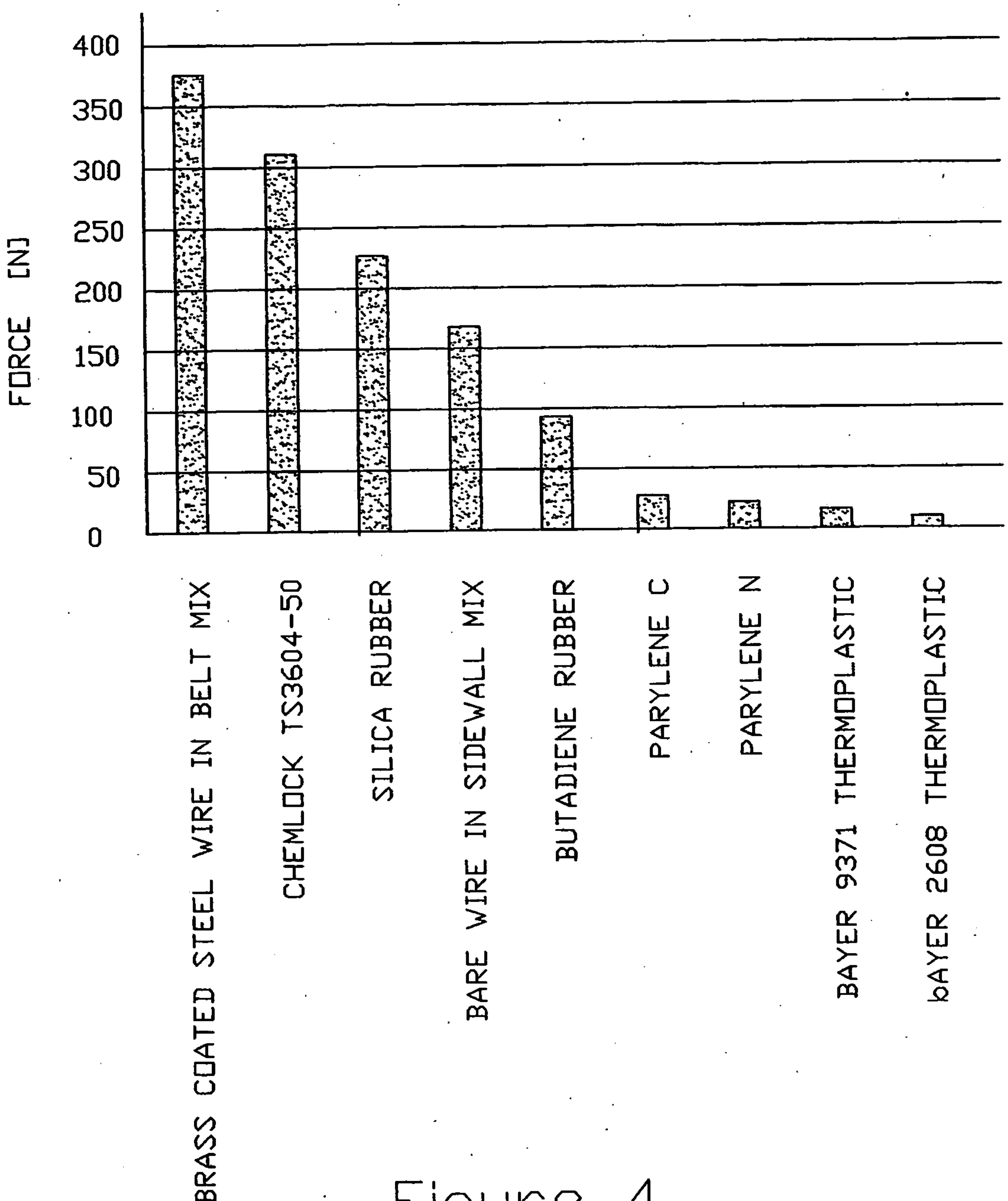
READ RANGE (INCHES)
45
40
35
30
25
20
15
10
5
0
ELECTRICAL SHRINK TUBING
THERMOPLASTIC POLYCARBONATE
BUTADIENE RUBBER
CHEMLOCK TS3604-50
THERMOPLASTIC POLYCARBONATE
POLYETHLENE
INSULATING VARNISH
EPOXY
TPE CELOUSE ACETATE
PARYLENE
INSULATING POLYESTAR VARNISH
NONE

Figure 3


FORCE [N]
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350
300
250
200
150
100
50
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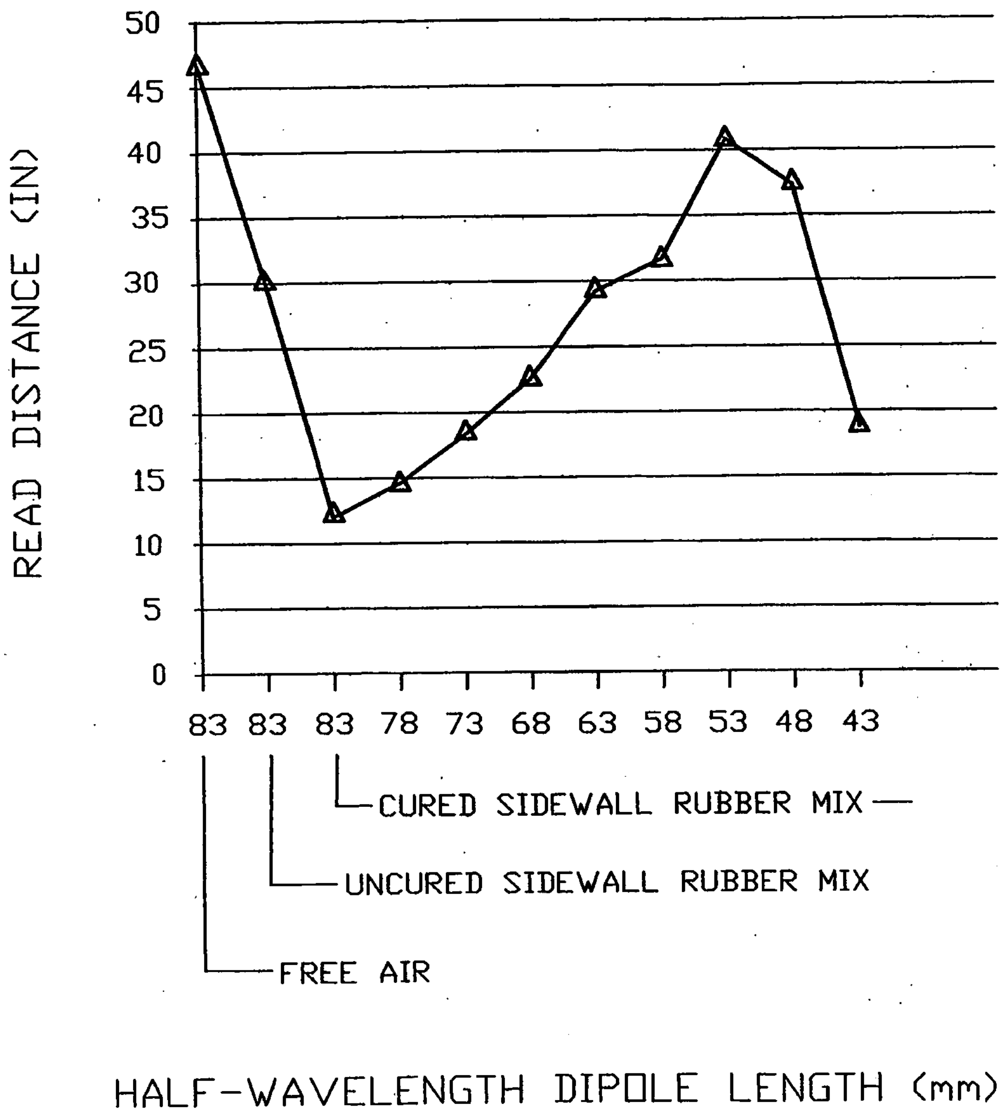
BRASS COATED STEEL WIRE IN BELT MIX
CHEMLOCK TS3604-50
SILICA RUBBER
BARE WIRE IN SIDEWALL MIX
BUTADIENE RUBBER
PARYLENE C
PARYLENE N
BAYER 9371 THERMOPLASTIC
bAYER 2608 THERMOPLASTIC

Figure 4


READ DISTANCE (IN)
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45
40
35
30
25
20
15
10
5
0
83 83 83 78 73 68 63 58 53 48 43
CURED SIDEWALL RUBBER MIX
UNCURED SIDEWALL RUBBER MIX
FREE AIR
HALF-WAVELENGTH DIPOLE LENGTH (mm)

Figure 5

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US02/18411

A. CLASSIFICATION OF SUBJECT MATTER
IPC(7) : H04Q 7/32
US CL : 340/442,443,447,438; 343/711; 200/61.22
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
U.S. : 340/442,443,447,438; 343/711; 200/61.22

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
NONE

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
EAST

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 6,147,659 A (TAKAHASHI et al.) 14 November 2000, see col. col. 2 lines 10-22, col. 4 lines 30-35, col. 6 lines 9-14, col. 7 lines 1-7.	1-4,6-10,12-14,18,20-24
A	US 6,271,748 B1 (DERBYSHIRE et al.) 07 August 2001, see col. 2 lines 35-41, col. 4 lines 53-60, col. 5 lines 5-7.	1-4,6-10,12-14,18,20-24
Y	US 4,911,217 A (DUNN et al.) 27 march 1990, see whole document.	1-4,6-10,12-14,18,20-24,

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

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"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

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"&" document member of the same patent family

Date of the actual completion of the international search 22 July 2002 (22.07.2002)	Date of mailing of the international search report 17 SEP 2002
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